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The Corrosion Resistance of Iron-Tin Compacts as Produced by Powder Metallurgy

Robert W. Gambill

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THE CORROSION RESISTANCE OF
IRON-TIN COMPACTS
AS PRODUCED BY POWDER METALLURGY

BY

ROBERT W. GAMBILL

MONTANA SCHOOL OF MINES LIBRARY
BUTTE

A Thesis

Submitted to the Department of Metallurgy
in Partial Fulfillment of
the Requirements for the Degree of
Bachelor of Science in Metallurgical Engineering

Montana School of Mines
Butte, Montana

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CHAPTER I

INTRODUCTION

The problem of this thesis is to determine the corrosion resistance of compacts produced from the metal powders of iron and tin.

These compacts were kept in the low tin range (maximum 10 per cent tin) and the corroding medium was a salt water atmosphere.

Variables were introduced within narrow limits and consisted of composition of compacts, sintering time, and time of exposure to the corroding atmosphere. The other possible variables had to be eliminated because of the limited time available for this problem.

The author believes that experimentation was justified on this topic because there is virtually no record of the corrosion resistance of iron-tin alloys, whereas, there is abundant literature on the effectiveness of tin in protecting iron and steel when applied as a covering to this metal.

OUTLINE OF THESIS

This thesis will include:

1. A short history of Powder Metallurgy.
2. Advantages of the Powder Metallurgy Process.
3. Limitations and problems of the Powder Metallurgy Process.
4. Cohesion of Metal Powders.
5. Manufacture of Metal Powders.
6. Importance of corrosion and the accepted theory of corrosion.
7. A description of the apparatus utilized for this problem.
8. Procedure followed in producing the compacts.
9. Method of determining corrosion resistance.
10. Experimental results and conclusions drawn from the results obtained.

CHAPTER II

POWDER METALLURGY

Basically, the art of Powder Metallurgy deals with the preparation of metal powders and their utilization, but this is too general and includes fields other than metallurgy. As a more pertinent definition, the following has been suggested: "Powder Metallurgy is the art of producing metal powders and shaped objects from individual, mixed, or alloyed metal powders, with or without the inclusion of non-metallic constituents, by pressing or forming objects which are simultaneously or subsequently heated to produce a coalesced, sintered, alloyed, brazed, or welded mass, characterized by the absence of fusion, or the fusion of a minor component only".¹¹

It is the common belief that Powder Metallurgy is a new field but actually it is hundreds of years old. The Hittites as early as 1300 B.C. were producing iron by reducing the ore to a spongy mass by a heat which was insufficient to fuse the iron. After reduction the mass was pressed, heated, and forged into the desired shape. This is essentially the basic process employed in the modern Powder Metallurgy industry.

Powders of gold, silver, copper, bronze, and lead were also produced very early in history. These early workers produced the powders more as a necessity than as a desirability because at this early date the furnaces used could not produce

high enough temperatures to fuse these metals. As furnace design improved and higher temperatures could be produced the production of metal powders passed out of the picture.

In the early part of the nineteenth century Wollastan developed a method of producing high purity platinum ware. He accomplished this by selecting only the finely divided platinum particles and compressing them while wet. The moisture allowed lower compacting pressures and prevented, to a considerable extent, the work hardening of the metal powder. After compacting the article was dried to remove all volatile matter and then sintered at 1000 degrees centigrade and hot forged to the desired shape. This process is essentially still used in England for obtaining platinum from metal powders.

Other advances in the field of metallurgy were shown during the subsequent years. Henry Bessemer was a large producer of metal powders during the late eighteen hundreds. It has been stated that the profits from his powder production financed the Bessemer Process for making steel.

In 1870 Gwyn patented the first self-lubricating bearing which was composed of 99 per cent tin and 1 per cent of petroleum residue.

Tungsten wire for lamp filaments was produced from metal powder by Collidge in 1909. This development opened the door for the fabrication of other refractory metals. Since that time the Powder Metallurgy industry has expanded many fold

till at the present time it is competing with some of the conventional methods used in fabrication.

ADVANTAGES OF THE POWDER METALLURGY PROCESS⁹

1. High purity of the metal content of the finished product can be maintained. The metal powders are 99 per cent or more pure metal and as no impurities are picked up during the process the original metal purity is retained and may even be improved by removing the oxide coating in a reducing atmosphere.
2. Chemical composition of the finished product can be completely controlled because of the fact that no oxidation or slagging occurs as in the other fabricating processes.
3. Materials not possible of fabrication by any other method can be produced by powder methods. These products include porous bearings, sintered carbides, refractory metals, and combinations of metals or of metals and non-metals which do not alloy.
4. High production rates of small parts can be attained by the use of automatic presses and continuous type sintering furnaces. This high rate of production does not apply to larger parts as they require individual attention.
5. A wide range of certain physical properties can be obtained for any particular material being fabricated. Control can be exercised over such properties as density, porosity, grain size, and strength by varying the type and size

of powder particles, die pressure, and sintering time and temperature.

6. Reasonably close tolerances can be secured without further machining. This factor is important because labor costs are reduced to a minimum.
7. There is usually very little material waste in the Powder Metallurgy process because there is virtually no scrap. Powder losses usually run below 0.5 per cent as compared to casting in which many times the weight of the desired product may be lost as scrap, and machining in which as much as 50 per cent of the metal is lost.
8. Highly skilled labor is not required for most of the operations in the Powder Metallurgy process. Skilled labor is required to make the dies but once these are produced their operation can easily be controlled by semi-skilled labor.
9. Tooling costs are usually lower than those for other high production methods, and less time is required to set up for production.

LIMITATIONS AND PROBLEMS OF THE POWDER METALLURGY PROCESS⁹

1. The cost of metal powders is high in comparison with metal used by other methods in producing the same part. However, this problem has been studied extensively in recent years

and with increased use of metal powders which stimulated powder production, the cost of these powders has been lowered and the variety of powders available has been increased.

2. Die expense is high, especially for large and complicated parts and where high pressures are employed. New dies are required for each new part of different size or shape and each die must be installed and carefully adjusted for operation.
3. Sintering furnaces present a problem in the Powder Metallurgy industry. Close control of temperature is necessary to obtain the desired qualities in the finished product. In sintering the refractory metals high temperatures are necessary and this adds to the difficulty of furnace design.
4. The size and form of the metal powder products are limited. Large compacts require huge presses to obtain the desired compacting pressure, thus both the tool and press costs go up. The larger compacts may have an unequal distribution of pressure on different parts of the compact which may effect the shape and dimensions of the article in the sintering operation. The low apparent density of most metal powders effects die design and limits the thickness of the parts produced. A compression ratio of about

3 to 1 is generally assumed, which means mold depth must be at least 3 times the thickness of the finished product.

5. The powder process is essentially one of mass production and a reasonable number of parts must, in general, be fabricated or the cost per unit will be excessive.
6. On a production basis powder metal structural parts generally have relatively low elongation, tensile strength, and impact strength. Because of the voids normally present in powder metal parts the ultimate properties cannot be expected to be as good as those obtained in cast and wrought materials.
7. There are a number of design limitations for powder metallurgy parts.
 - a. Sharp corners should be avoided and internal angles should have fillets.
 - b. Large and abrupt changes in thickness should be avoided, as should uneven cross-sections.
 - c. Re-entrant angles, grooves, and undercuts cannot be molded, and if required must be machined in an extra operation. Internal and external threads as well as holes perpendicular to the axis of pressing cannot be formed.
 - d. Lengths of pressed parts must be limited because of the tendency for long sections to have a soft central portion of low density.
 - e. There is no flow of metal powder during pressing.

8. To obtain close tolerances on irregular or concentric parts machining is necessary.
9. At the present time there is a definite lack of technical information available to designers. Steps are now being taken to standardize tests for metal powders as well as for finished compacts. This step is of great importance in promoting the Powder Metallurgy industry.
10. The oxides of some metals have a higher reducing temperature than the melting point of the metal itself which prevents effective welding of the powder particles.
11. Metal powders in a fine state of subdivision are readily combustible and must be considered as potential fire and explosion hazards. Precautions must be taken in the mixing rooms to overcome these hazards as well as removing any possible toxic effect the dust may have on the workers.
12. Deterioration of powders may occur in storage due to oxidation and moisture which may change the chemical composition of the powder.

COHESION OF METALS³

In compacting powder into parts it is necessary to apply a minimum of pressure to the powder. The pressure brings the individual particles into close contact with other individual particles so that the atomic surface forces are exerted. The actual welding process is due to these atomic surface forces which in turn are dependent on the completeness of the contact between the particles.

To promote contact between the particles the temperature during pressing may be raised or a sintering operation may follow the compacting. This increases the mobility of the atoms diffusing across the contact interface.

Increased compacting pressure also promotes contact but this approaches a limit at high pressures above which it is not economical to increase the pressure.

The smaller the particles the greater the adhesion. This is probably due to the fact that more contact is obtained because of increased area per unit weight.

MANUFACTURE OF METAL POWDERS^{1,9}

Metal powders are made in a variety of ways each method of preparation suited to the metal being treated, or the end product desired. By the use of various methods of producing powders a large range of physical properties can be obtained for the same metal.

Of the many methods of production possible, relatively few are actually employed on a large commercial scale.

All of the various methods known fall into three general classes, as follows:

1. Mechanical--machining, milling, shotting, granulation, atomizing, and condensation.
2. Physical--electrodeposition and carbonyls.
3. Chemical--reduction, precipitation, and chemical reaction.

The bulk of the metal powders are produced by three of the above methods.

1. Electrodeposition.
2. Atomizing.
3. Reduction.

CHAPTER III

BASIC PRINCIPLES OF METALLIC CORROSION

IMPORTANCE²

Nearly all of the known metals appear as compounds of the earths crust. Only a few of the nobler metals appear in the metallic state. Likewise, the pure metals produced by man from these compounds tend to alter upon exposure to atmospheric conditions. The solid corrosion products thus formed are of the same composition as certain of the naturally occurring compounds of the metal. Such observations tend to prove that these compounds are a more stable form than the pure metals and therefore, it should be expected that metals will corrode.

The problem at hand is to devise methods for retarding or preventing this corrosion. Each year large tonnages of the annual production is lost as corrosion products but this is of secondary importance as compared to the loss of life due to accidents directly or indirectly caused by corrosion. Less spectacular is the effect of the corrosion products (as in food containers) upon the health of mankind.

THEORY OF CORROSION^{2,4,5,10}

Several theories have been advanced from time to time to account for corrosion of metals. At the present time "The Electrolytic Theory of Corrosion" is the most

generally accepted theory.

It is professed in this theory that corrosion is a purely electrochemical reaction. It is based on the reaction which takes place when two dissimilar metals are in contact in the presence of an electrolyte. It is known that in such a couple a galvanic cell is set up in which the metal higher in the electrochemical series is anodic as compared to the less active metal. The anodic metal goes into solution and is subsequently precipitated as the hydroxide. Therefore, the more active metal is corroded.

This same condition can easily exist in supposedly homogeneous metals and alloys, with localized areas of the metal having higher electrochemical activity than the surrounding metal. Such a condition can be caused by a variety of circumstances.

1. Oxygen concentration cell. This can be shown in a metal which is covered by drops of electrolytes or between two pieces of the same metal placed closely together, allowing only a thin film of electrolyte to come between them. In such cases the oxygen concentration at the edges closer to the air will be higher than at the interior. This condition will cause the portion with the lesser oxygen concentration to be anodic as compared to the outer part.

2. Such a condition can also be explained as follows: The iron replaces the hydrogen in the solution and hydrogen gas is formed. This gas adheres to the metal and reduces the corrosion taking place. However, the portion of the electrolyte exposed to the air supply absorbs oxygen which combines with the hydrogen to form water. This causes polarization in which the hydrogen covered portion is anodic in character.
3. Stress set up in the metal will cause galvanic corrosion at the stressed portion as this portion has a higher electrochemical activity than the parent metal.
4. Inclusions in metals will cause electrochemical corrosion. These impurities may be very minute in character and appear between the grains of the metal such as in brass.
5. Different portions of the same electrolyte may have different concentrations and on the same metal this will have an electrochemical effect.

CHAPTER IV

DESCRIPTION OF APPARATUS AND EQUIPMENT

WEIGHTING AND MIXING APPARATUS

An analytical balance was used to weigh the metal powders prior to compacting. Mixing was accomplished in a regular sized test tube.

PRESSING EQUIPMENT (Fig. 1)

The pressing equipment was comprised of a mold and its accessories, a hydraulic jack, and a frame for supporting the mold and jack.

The mold consists of three parts, the mold proper, the plunger or ram, and the top plug. These parts are machined from steel. The mold proper is divided into halves along the vertical axis and the two halves are held together by 6 bolts. This arrangement facilitates cleaning of the mold and also aids in removing the ram in case it should stick in the mold. (Plate I)

The frame for the pressing apparatus consists of four rods welded to a square steel plate and provided with other plates which can be adjusted to the desired position.

The large hydraulic jack has rated capacity of 50,000 lbs. on a plunger diameter of 2.562 inches.

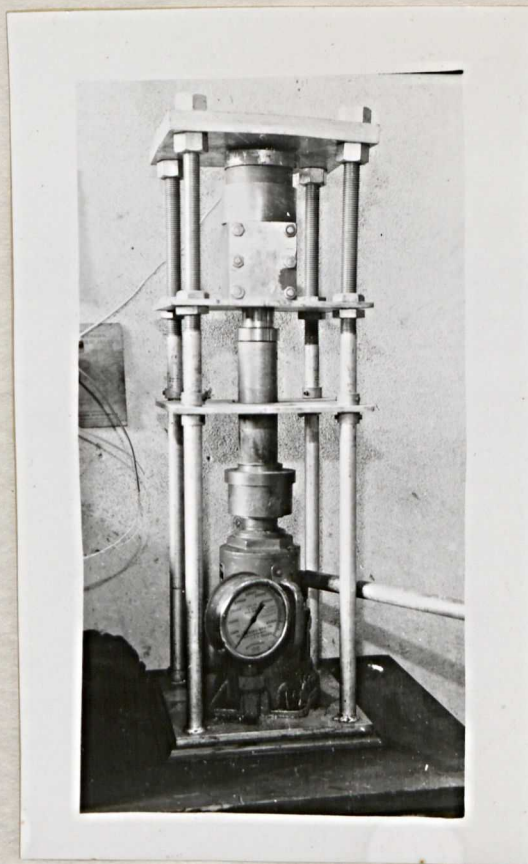


Fig. 1
Pressing Equipment

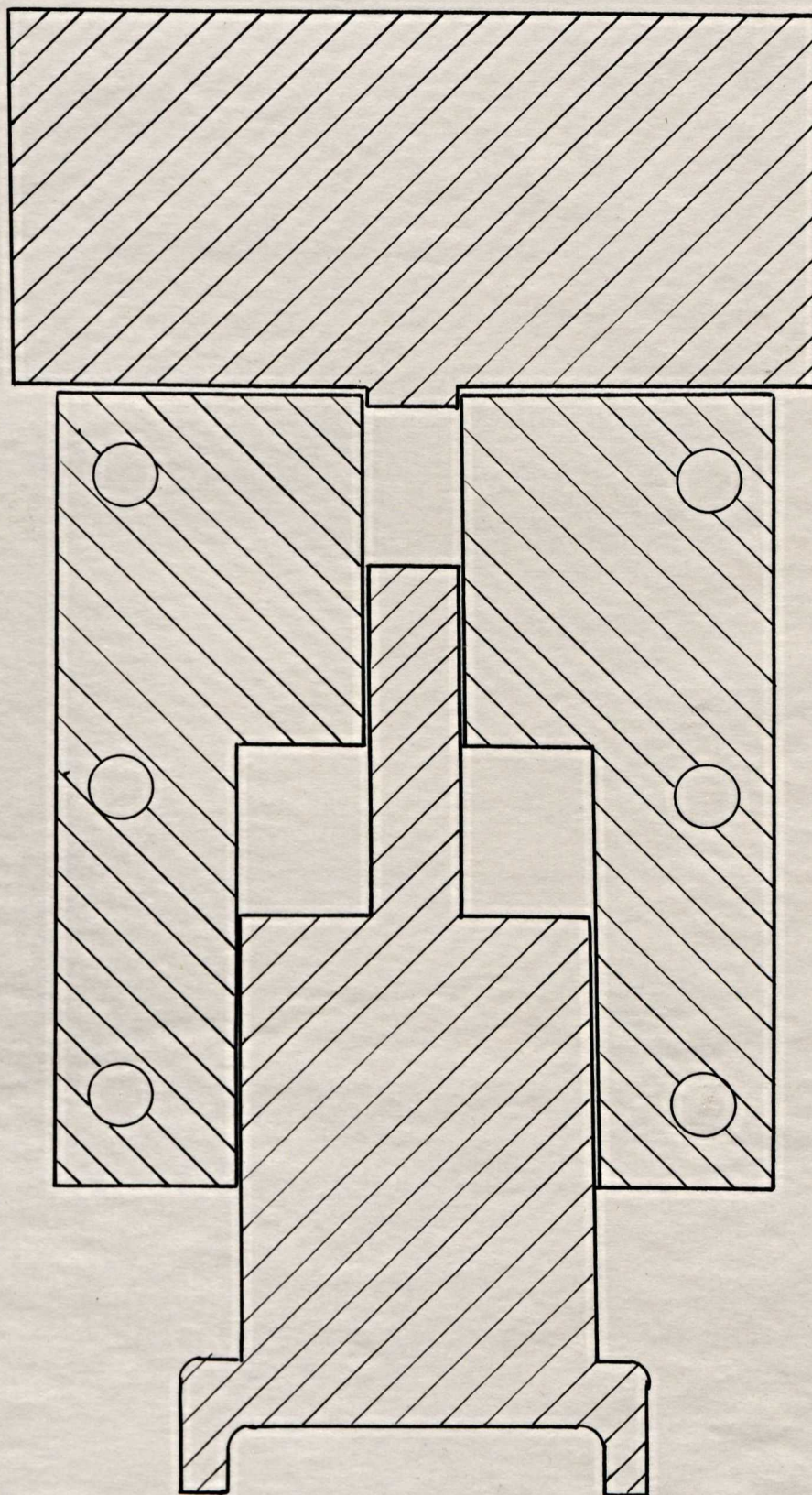


PLATE I
MOLD

Scale-Full Size
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May 8, 1947

SINTERING EQUIPMENT

The sintering operation was accomplished in a quartz tube electric furnace. The temperature was regulated by a reostat in series with the heating element of the furnace. The tube of the furnace is equipped so the atmosphere can be controlled. (Fig. 2)

CORROSION EQUIPMENT

The salt spray apparatus selected for this problem was patterned after that described by Rawdon, Krynitsky, and Finkeldey.⁸ (Fig. 3) It consists of an albertine stone box in which the specimens were placed and where corrosion took place. The box was equipped with glass rods to hold the samples, a glass baffle plate to prevent direct impingement of the solution upon the samples, an atomizer to produce a fine mist, an inlet for air, and an exhaust for spent mist. The box was covered by a glass plate and vasoline was used to seal the cover to the box. (Plate II)

The air used by the atomizer to produce the mist was provided by the compressor through the main air line. Before entering the box the air was passed through a series of five bottles the first of which was filled with glass wool to collect any dirt or oil which might be present in the air. The remaining four bottles were partially filled with water to allow the air to become thoroughly saturated with moisture

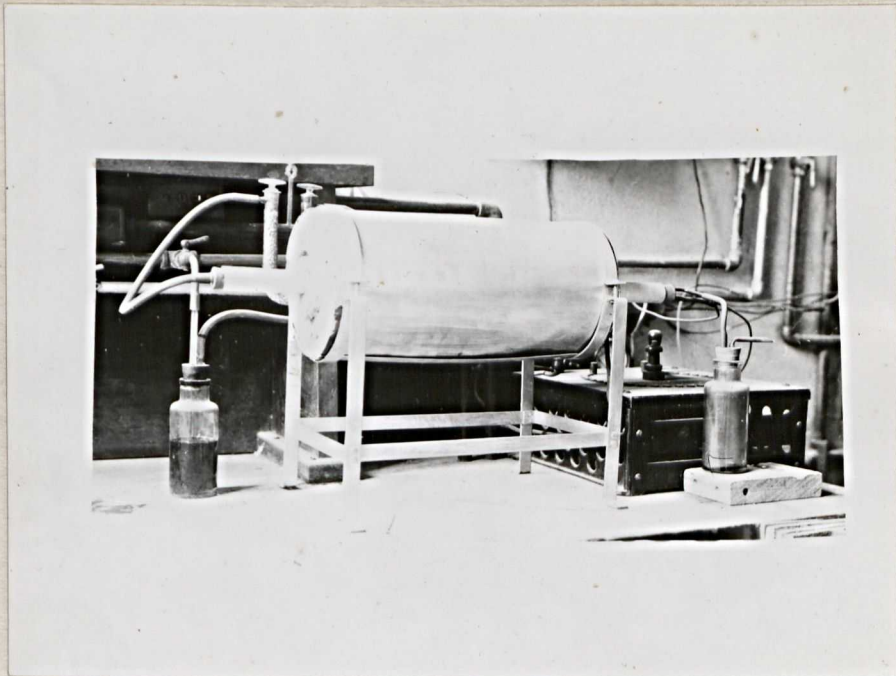
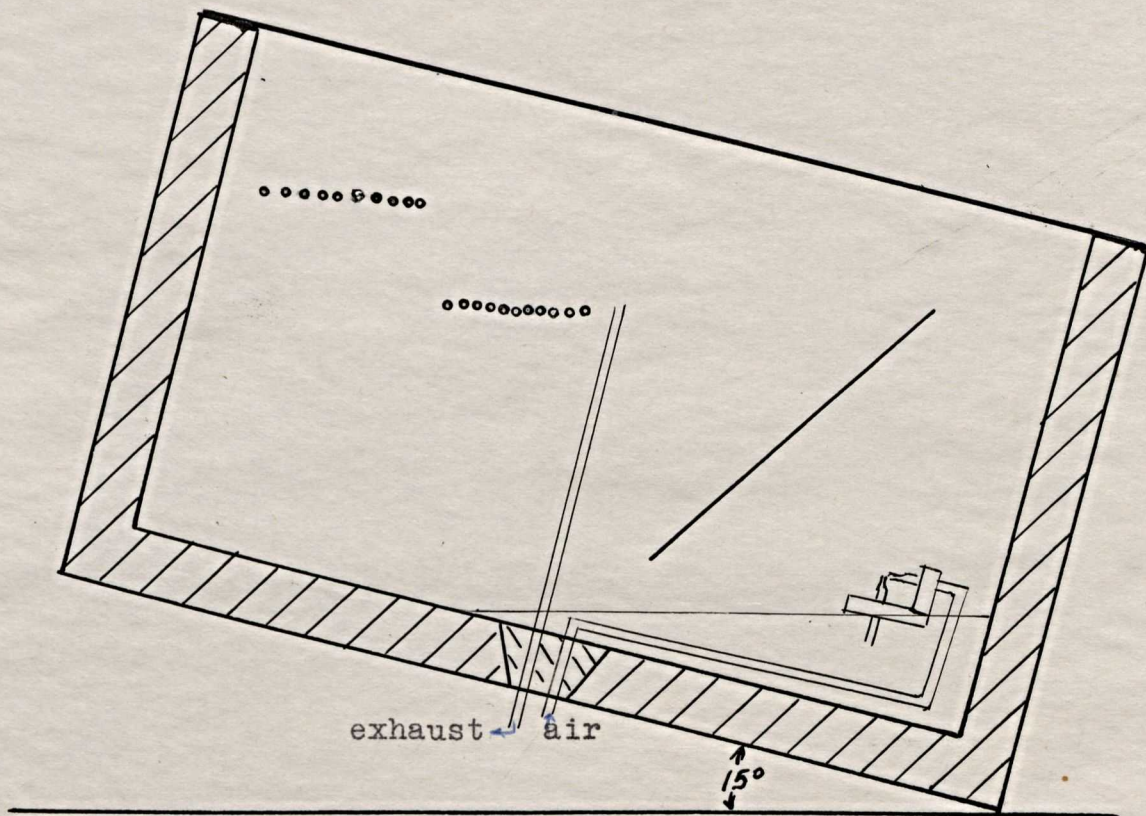


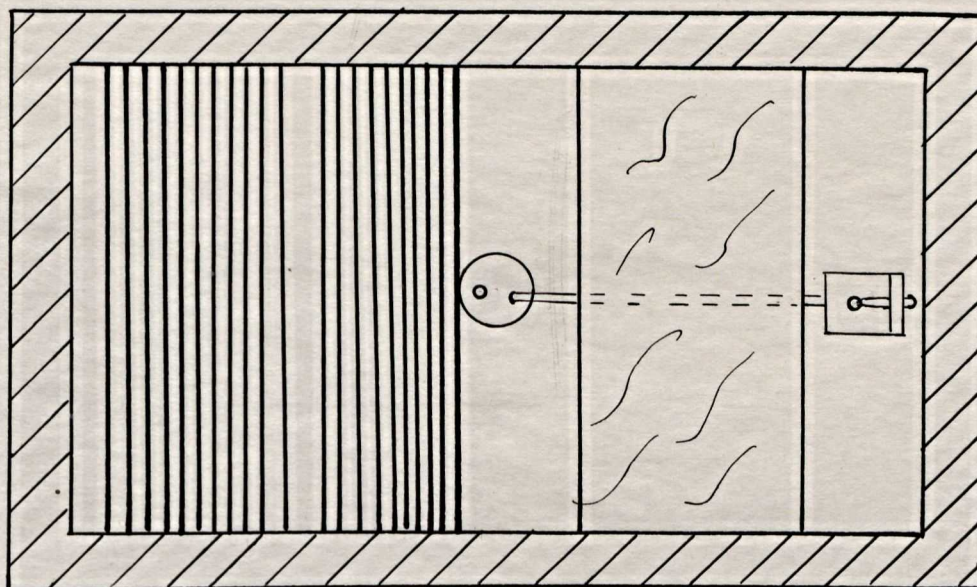
Fig. 2
Sintering Equipment



Fig. 3
Corrosion Equipment



SIDE VIEW



VIEW PERPENDICULAR TO TOP

PLATE II
CORROSION MACHINE

Scale - $\frac{1}{4}'' = 1''$
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May 8, 1947

thereby maintaining a more constant concentration of solution within the box.

The air pressure was maintained at a monometer reading of twelve inches of mercury (approximately 5.9 lbs. per sq. in.). As an aid in maintaining a constant pressure at the atomizer a column of mercury was placed in the air circuit prior to the first bottle. This mercury column was of sufficient diameter to allow air to escape through it if the pressure should become too high.

CLEANING EQUIPMENT

An electrolytic cleaning process was used to clean the corrosion products from the specimens.⁶ (Plate III) The requirements of the process are as follows:

Solution (electrolyte)	-- 5% by weight H_2SO_4
Anode	-- Carbon
Cathode	-- Specimen
Cathode C.D.	-- 20 amps per sq. dm.
Inhibiter	-- 2 c.c. formaldehyde per liter of solution
Temperature	-- 165° F. (74° C.)
Exposure time	-- 3 minutes

A six volt battery was used as a power source. The circuit included a reostat to control the current density, an ammeter, a voltmeter, and the electrolytic cell. A cylindrical glass dish was used for the cell and the temperature was controlled by placing the cell in a bath of hot water.

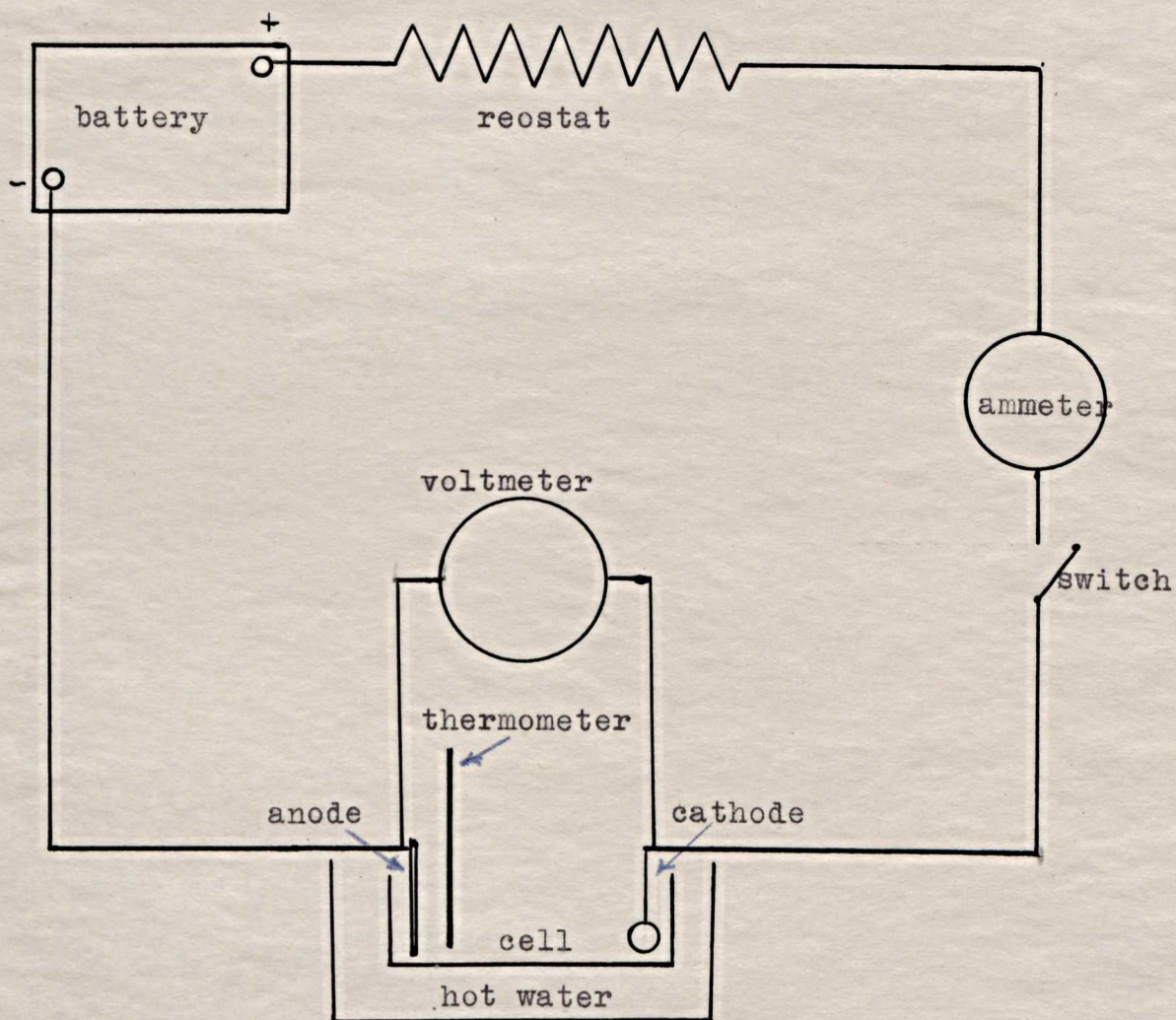


PLATE III
ELECTROLYTIC CLEANING CIRCUIT

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CHAPTER V

PROCEDURE USED IN PRODUCING COMPACTS

SELECTION OF POWDERS

The powders used in the compacting of the specimens were the metal powders available in the laboratory. These powders were presumed to be pure metal thus neglecting any oxide coating which might have been present. Each powder was screened on a Standard Tyler Screen and the following information resulted.

Ninety per cent of the iron powder passed through a 200 mesh screen and about 99 per cent of the tin powder passed through a 325 mesh screen. The difference in the sizes of the two powders will give a wide range of sizes with in the mixtures of powders. This, in turn, will give fewer voids in the finished compact as the smaller tin particles will tend to sift into the large openings between the larger iron particles.

WEIGHING AND MIXING

The metal powders were weighed to the nearest milligram on an analytical balance. The above accuracy in weighing was adequate for the 10 gram samples fabricated. The proper weight of each powder necessary to produce the desired percentage ratio was then placed in a standard test tube and this test tube was tightly corked. The powders

were then thoroughly mixed by rolling the test tube for a two minute period.

It was desired to have compacts measuring approximately one-half inch in length. A few sample compresses were made and from these a total sample weight of 10 grams was decided upon.

Nine compacts of each of the following compositions were necessary for the problem.

	Weight (grams)		Percentage	
	<u>Iron</u>	<u>Tin</u>	<u>Iron</u>	<u>Tin</u>
1.	10.00	0.00	100	0
2.	9.80	0.20	98	2
3.	9.60	0.40	96	4
4.	9.40	0.60	94	6
5.	9.20	0.80	92	8
6.	9.00	1.00	90	10

PRESSING OPERATION

The mold was made ready for the pressing operation by raising the ram to the desired position in the mold. The ram was high enough in the mold to prevent leakage of powder past the ram yet low enough to give room for the uncompacted powders. When this preliminary step had been completed the mixed powder was fed into the mold with the aid of a funnel. The funnel was then removed and the top plug placed in position

and subsequently blocked against the top plate of the frame. The entire apparatus was inspected for alignment and when so aligned was in readiness for the operation.

One compacting pressure was decided upon for fabricating all specimens. To ascertain the best pressure to be used a few test compacts were made. The pressures used were:

1. 15,000 lbs. gage pressure.
2. 20,000 lbs. gage pressure.
3. 25,000 lbs. gage pressure.

The test samples subjected to the lowest pressure of 15,000 lbs. gage were easily formed but their structure was much too weak to be of practical use.

On the other extreme the samples fabricated at the high pressure had very desirable properties but were characterized by sticking in the mold thus presenting a difficulty in fabrication.

The middle path of 20,000 lbs. gage pressure was selected as the compacting pressure for this particular problem. The compacts produced at this pressure were strong enough to sustain rough handling and also did not stick in the mold during compacting.

The compacting was now begun on the desired samples. The pressure of 20,000 lbs. gage was applied and held for one minute. When this time had elapsed the pressure was released and the plug and blocking plates removed from the top of the

mold. The plug was replaced by a block with a hole in it and the other blocks were replaced to the original position. Pressure was again applied to the ram and the finished compact ejected from the mold.

Carbon is often used to lubricate the mold but the pressure used in this operation made this step unnecessary.

SINTERING

The compacts were now ready to be sintered and this was done in the quartz tube furnace described above.

It was necessary to keep the sintering temperature below the melting point of tin to prevent the loss of tin by melting it out of the compacts. A convenient temperature of 200° C. was chosen.

At this point another variable was introduced by using three different sintering times. These sintering times were 6 hours, 12 hours, and 24 hours. Three compacts of each composition were subjected to one of the above sintering periods.

A neutral atmosphere of methane (natural gas) was maintained about the compacts during sintering. The gas was used from the supply line and was circulated through oil and calcium chloride to remove any dust or moisture which might have been present before entering the furnace. The gas was burned at the discharge end of the tube furnace.

CHAPTER VI

CORROSION RESISTANCE

CORROSION

The sintered compacts were placed on the glass rod racks within the corrosion machine and corrosion commenced.

A one normal sodium chloride solution was used as a corroding medium. A dense mist of this medium was maintained within the box by the atomizer. Three liters of solution were required to enable the atomizer to function properly. Once a week the old solution was removed, the box rinsed out with clear water, and new solution added. This operation removed the corrosion products which had become detached from the compacts and had polluted the solution.

After two weeks of exposure the first set of samples was removed from the box. One set consists of 18 compacts, 3 of each composition, each one of the 3 having been given a different sintering treatment.

CLEANING OF SAMPLES

The corroded samples had to be cleaned to remove all corrosion products. Firstly, the rust was scraped off with a knife care being taken not to remove any of the original metal. The bulk of the rust was thus removed. This operation was followed by scrubbing the samples with a stiff

wire brush in the presence of water. Because of the porous nature of the compacts the above operations did not remove all of the corrosion products. This necessitated the use of the electrolytic cleaning apparatus. With the aid of this mechanism a more thorough cleaning could be obtained.

MEASUREMENT OF CORROSION

The method employed to determine the amount of corrosion which had taken place was the "loss of weight method". This method is as follows:

1. The clean samples are weighed before exposure to the corrosive atmosphere.
2. The clean samples are weighed after exposure to the corrosive atmosphere.
3. The total loss of weight in milligrams is obtained by difference.
4. The total loss is converted to the generally accepted method of recording corrosion losses which is loss in milligrams per sq. decimeter per day. This is accomplished as follows:

$$\frac{(\text{loss in mg.})(24)}{(\text{specimen area-sq.dm.})(\text{time-hrs.})} = \text{mg loss/dm}^2/\text{day}$$

The surface area of all compacts was the same. They had a diameter of 12.83 mm. and a length of 12.5 mm. These values gave a surface area of 7620 sq. mm. or 0.0762 sq. dm.

CHAPTER VII

EXPERIMENTAL RESULTS

The specific results obtained from this problem were derived from three sets of samples. Set number one was exposed to the salt mist for two weeks, set number two for four weeks and set number three for six weeks. The designation used to identify the samples was as follows:

1. The first number represents exposure time in weeks.
2. The middle number represents the percentage of tin in the compact.
3. The final number represents the sintering time in hours.

Example: 2-4-12 means 2 weeks exposure on a 4% tin sample which has been sintered for 12 hours.

Set No. 1

Exposure time 335 hrs.

Sample	Original Wt. grams	Final Wt. grams	Total loss milligrams	Loss mg/dm ² /day
2-0-6	10.127	10.172	-45	-42.3
2-0-12	9.890	9.784	106	99.6
2-0-24	10.145	10.044	101	95.0
2-2-6	10.025	9.930	95	89.4
2-2-12	10.060	10.028	32	30.1
2-2-24	10.005	9.972	33	31.0
2-4-6	10.035	9.950	85	80.0
2-4-12	10.063	9.900	163	153.0
2-4-24	10.030	9.980	50	47.0
2-6-6	10.015	9.952	63	59.0
2-6-12	10.025	9.910	115	108.0
2-6-24	10.030	9.930	100	94.0
2-8-6	10.010	9.948	62	58.3
2-8-12	10.010	9.904	106	99.6
2-8-24	10.010	9.870	140	131.6
2-10-6	10.020	9.850	170	160.0
2-10-12	9.997	9.862	135	127.0
2-10-24	9.985	9.876	109	102.5

Set No. 2

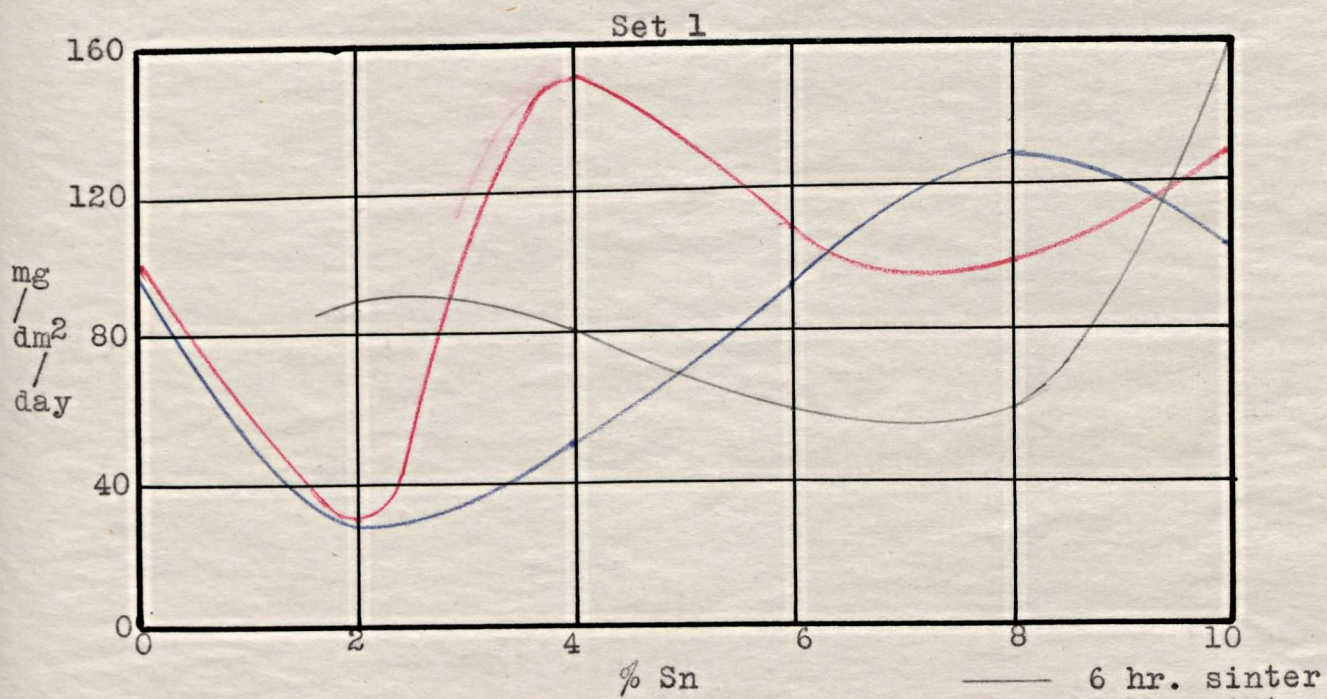
Exposure Time 669.5 hrs.

Sample	Original Wt. grams	Final Wt. grams	Total loss milligrams	Loss mg/dm ² /day
4-0-6	10.110	10.152	-42	-19.8
4-0-12	10.085	10.156	-71	-33.4
4-0-24	10.115	10.062	53	25.0
4-2-6	10.080	10.066	14	6.6
4-2-12	10.002	9.984	18	8.5
4-2-24	9.985	9.840	145	68.2
4-4-6	10.013	9.962	51	24.0
4-4-12	10.025	9.844	181	85.1
4-4-24	10.048	9.962	86	40.5
4-6-6	10.040	9.964	76	35.8
4-6-12	10.005	9.938	67	31.6
4-6-24	10.037	9.930	107	50.4
4-8-6	10.000	9.960	40	18.8
4-8-12	10.020	9.942	78	36.8
4-8-24	10.030	9.832	198	93.2
4-10-6	10.010	9.790	220	103.6
4-10-12	10.000	9.846	154	72.5
4-10-24	9.990	9.828	162	76.2

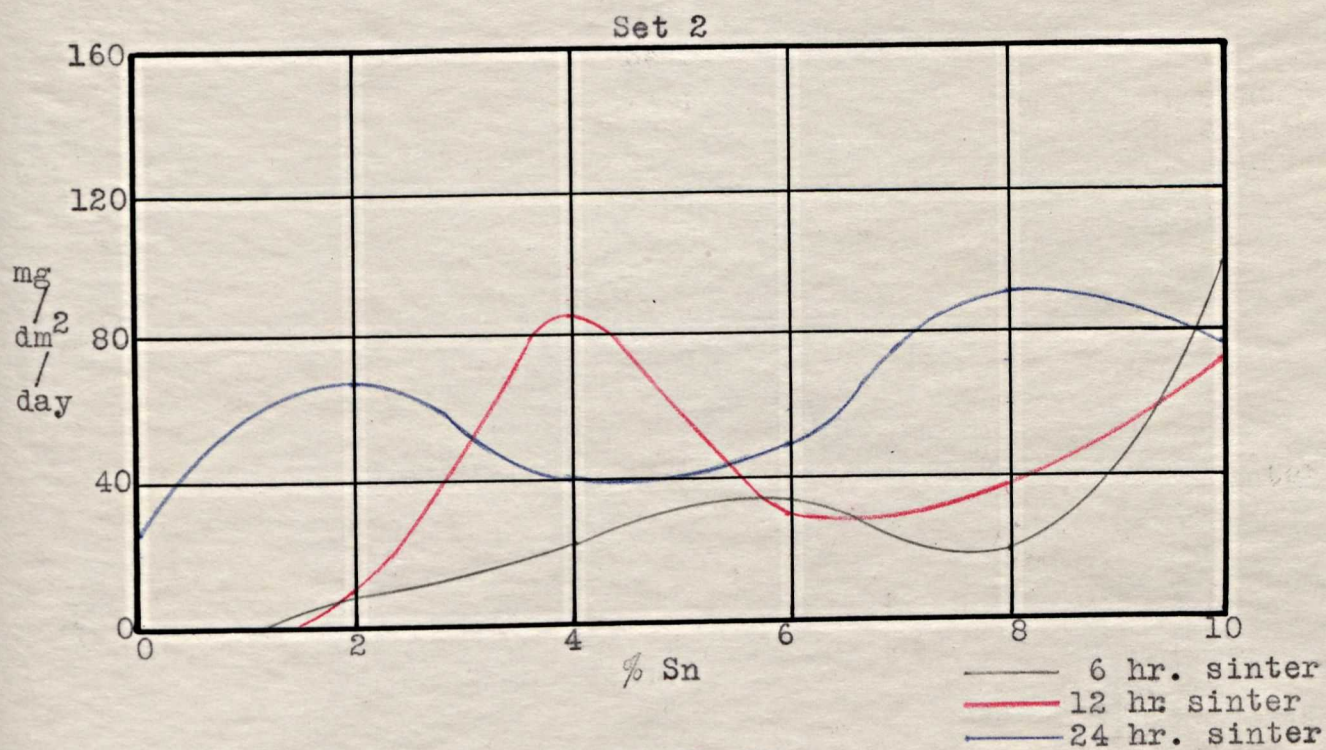
Set No. 3

Exposure Time 1005.0 hrs.

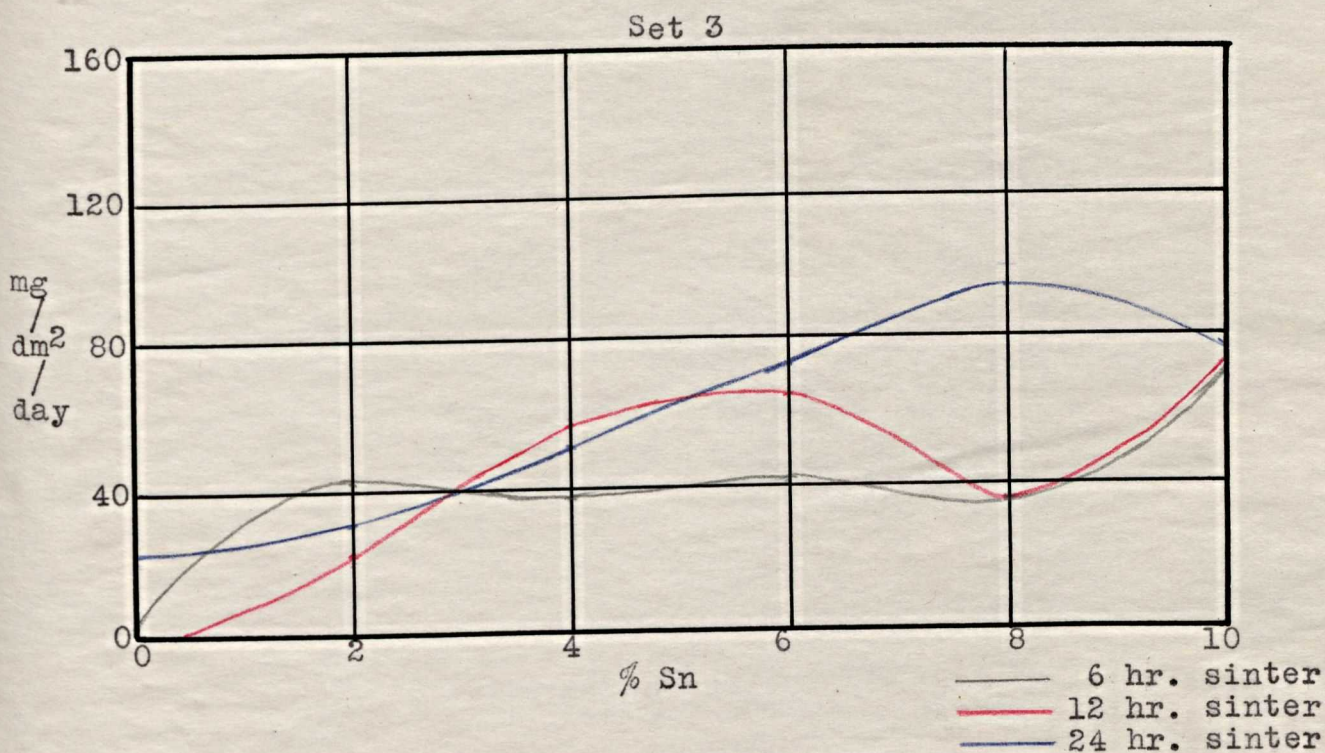
Sample	Original Wt. grams	Final Wt. grams	Total loss milligrams	Loss mg/dm ² /day
6-0-6	10.055	10.052	3	0.9
6-0-12	10.125	10.138	-13	-4.1
6-0-24	10.070	9.993	77	24.2
6-2-6	10.062	9.930	132	41.4
6-2-12	10.018	9.944	74	24.3
6-2-24	9.940	9.848	92	28.8
6-4-6	10.020	9.922	98	30.7
6-4-12	9.945	9.762	183	57.4
6-4-24	10.052	9.884	168	52.6
6-6-6	10.030	9.900	130	40.8
6-6-12	10.047	9.842	205	64.2
6-6-24	10.025	9.788	237	74.3
6-8-6	10.007	9.890	117	36.7
6-8-12	9.995	9.880	115	36.0
6-8-24	10.082	9.782	300	94.0
6-10-6	9.990	9.760	230	72.1
6-10-12	10.000	9.762	238	74.6
6-10-24	9.975	9.690	285	89.4



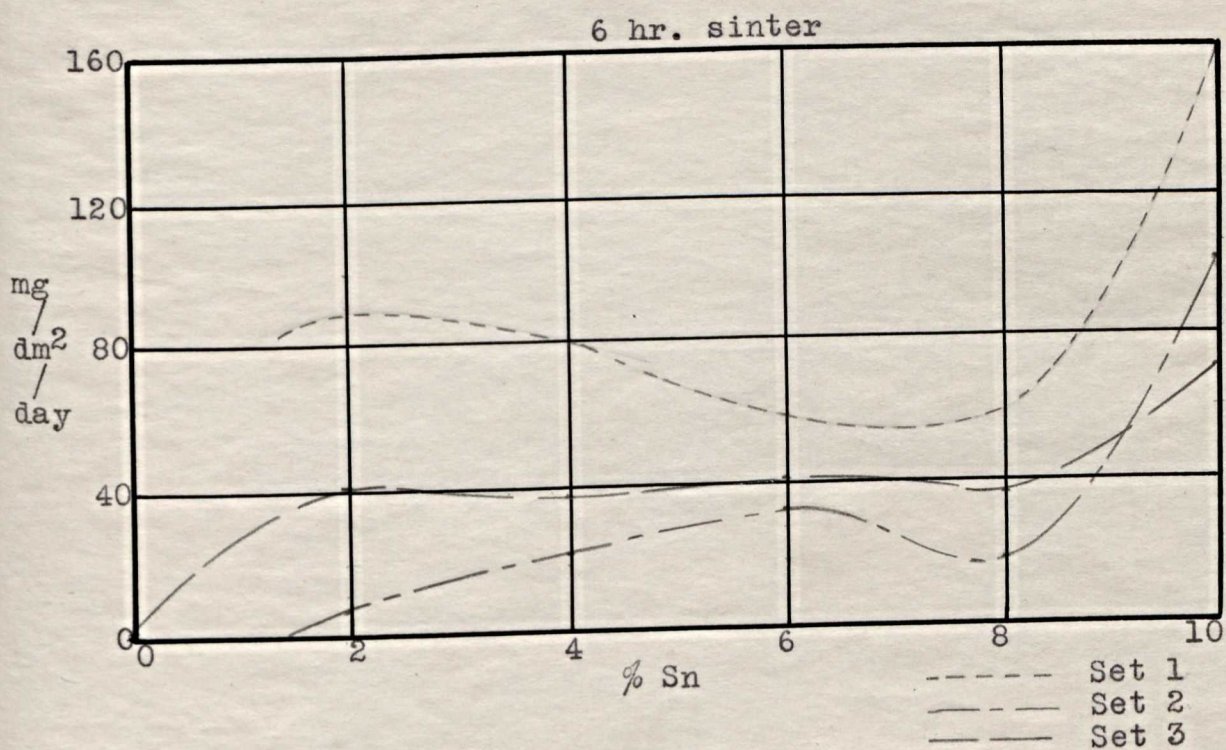
GRAPH I



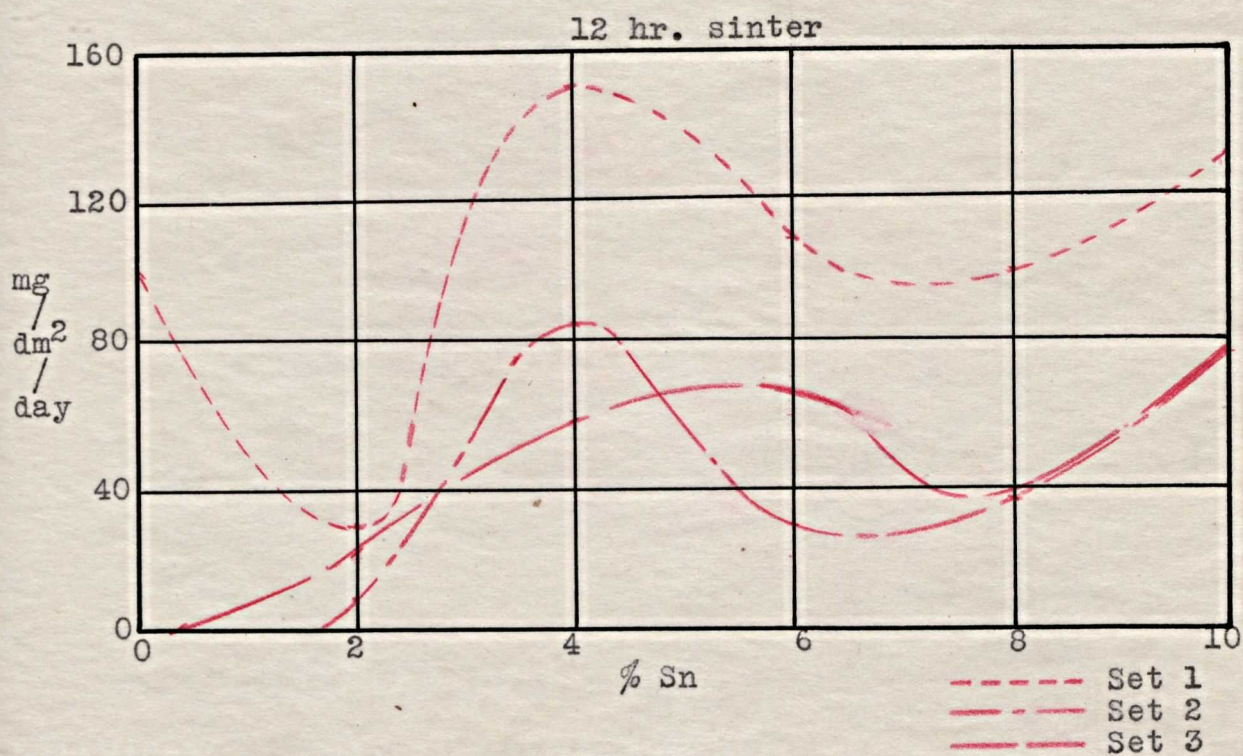
GRAPH II



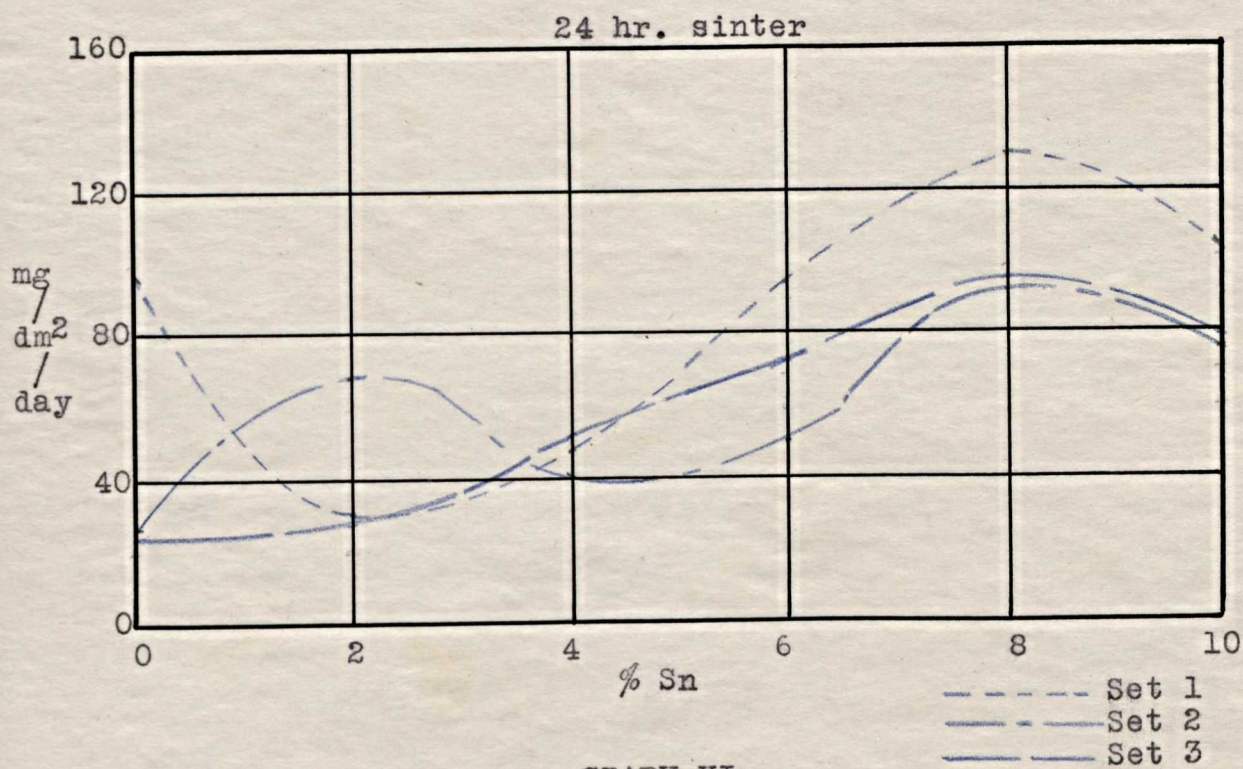
GRAPH III



GRAPH IV



GRAPH V



GRAPH VI

RESULTS OF VARIABLES ON CORROSION

1. Composition - As a general statement it can be said that as the percentage of tin was increased corrosion resistance of the compact decreased. This would tend to show that a solid solution of the two metals was not formed. This is possible because of the large difference between the melting points of the two metals. The sintering temperature was very small compared to the melting point of iron, therefore, no appreciable diffusion of the metals took place. Thus, the two metals existed in the pure form and in intimate contact with each other. In the presence of the solution a galvanic cell was set up in which the iron particles became anodic and consequently were subjected to accelerated corrosion.
2. Sintering Time - The effect of this variable is very hard to interpret. There was no distinctive effect caused by the sintering time. One might, after studying the various curves presented, conclude that the corrosion resistance decreased with increased sintering time. The author can offer no explanation for this tendency.
3. Time of Exposure to the Corroding Media - It seems that the maximum rate of corrosion occurred when the compacts were first exposed to the salt spray. This can be explained if one considers that the corrosion products formed prevent the solution from coming in contact with the metal as readily as when the compacts were clean.

CHAPTER VIII

CONCLUSIONS AND FURTHER RESEARCH

CONCLUSION

The author is of the impression that compacted parts produced from the powders of iron and tin should be discarded as a possibility for a corrosion resisting material. This, however, does not hold true for the alloys of iron and tin produced by fusion methods. McDonald's investigation of the low tin alloys of iron show that the corrosion resistance of these alloys is higher than that of ordinary iron.⁷

In general it would seem that if metal powder compacts having good corrosion resistance were desired the constituent powders should have melting points of approximately the same figure so that diffusion would be more complete. Good corrosion resistance might also be obtained by compacting powders of metals having approximately the same position in the electrochemical series.

Iron-tin compacts have neither of the above qualities, therefore, it would appear that these compacts have no application as a corrosion resisting material.

SUGGESTIONS FOR FURTHER RESEARCH

One phase of the production of iron-tin compacts could be given further investigation. It would be inter-

esting to press these powders at an elevated temperature (somewhat above the melting point of tin). It may be possible to prevent the loss of tin from the compact by maintaining this maximum pressure during the sintering operation. In such a case the tin and iron might form a solid solution which in turn would increase the corrosion resistance of the compact.

It might also be interesting to replace the tin used for this problem by some other corrosive resisting metal having a higher melting point. The effect of sintering time could be more closely studied on such a compact.

The effect of different corroding media might be studied to determine usefulness under different conditions. Both acid and alkaline solutions could be employed on the same product and a comparison made between the two.



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